Check List the journal of biodiversity data

NOTES ON GEOGRAPHIC DISTRIBUTION

Check List 17 (6): 1615–1622
https://doi.org/10.15560/17.6.1615

PENSOFT

First record of non-native *Xiphophorus maculatus* (Günther, 1866) (Cyprinodontiformes, Poeciliidae) in the state of Maranhão, northeastern Brazil

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Abstract

During a field expedition in 2020, we recorded specimens of an invasive platy fish, *Xiphophorus maculatus*, in the state of Maranhão, Brazil. This new occurrence, in the Municipality of São Luis, is only the second time that this non-native species has been found in northeastern Brazil. We provide an updated list of all invasive species recorded from the island of São Luís, highlighting the negative impacts they may confer for the native biodiversity.

Keywords

Cyprinodontoidei, freshwater, geographic distribution, invasive species, Neotropical region, poeciliids, South America

Academic editor: Victor De Brito | Received 4 August 2021 | Accepted 8 November 2021 | Published 23 November 2021

Citation: Ottoni FP, Guimarães EC, Santos JP, Brito PS, South J, Bragança PHN (2021) First record of non-native *Xiphophorus maculatus* (Günther, 1866) (Cyprinodontiformes, Poeciliidae) in the state of Maranhão, northeastern Brazil. Check List 17 (6): 1615–1622. https://doi.org/10.15560/17.6.1615

Introduction

Poeciliidae *sensu* Bragança et al. (2018), popularly known as livebearers, comprises 275 valid species of fish (Fricke et al. 2021a). These occur in the Americas mainly in both fresh- and brackish-water environments, but they also being reported from saltwater and even hypersaline environments (Trexler 1989), with the highest species diversity in Central America (Rosen and Bailey 1963; Lucinda 2005; Reznick et al. 2017). Species belonging to this family are easily recognized by the presence a copulatory organ in males, the gonopodium, consisting

of a modification of the anal-fin rays 3, 4, and 5 (Regan 1913; Rosen and Gordon 1953), as well as the presence of viviparity (matrotrophy) or ovoviviparity (lecithotrophy) (Rosen and Bailey 1963). Poeciliids include well-studied species such as guppies, *Poecilia reticulata* Peters, 1859, which are commonly used as experimental or model organisms in various areas of science, such as embryology, behaviour, ecology, and evolution. Moreover, they are very popular among aquarium hobbyists due to their bright colors, generalist life history traits, and ease of breeding in captivity (Lucinda 2005).

The poeciliid genus *Xiphophorus* Heckel, 1848 comprises 26 valid species (Fricke et al. 2021) and has a native distribution in Central America. According to Rosen (1979), *Xiphophorus* is readily distinguished from the other poeciliid genera by the possession of a unique microanatomy of the gonopodium tip (Rosen 1979: fig. 29). The distal portion of the gonopodium ray 3 possesses a large decurved hook followed by a series of simple segments and a series of elongate, ventrally directed and converging spines. The blade is a large, laterally compressed, calcified mass of granular tissue arising from the dorsal margin of the ray 3 terminal hook; the distal ramus of ray 4a curves downwards, conforming to the shape of the blade; there are two series of serrae separated by undifferentiated segments distally on ray 4p; ray 5a bends down towards ray 4p contacting the undifferentiated segments of ray 4p just proximal to the distalmost serrae of that ray; and rays 6 and 7 are swollen and clublike distally. In addition, the pelvic fins of species of this genus are modified, possessing an enlarged tip in the first ray, and with the second and third rays elongated (Rosen 1979). During mating, males swing their gonopodium forward, placing it against the erected pelvic (Clark and Kamrin 1951; Clark et al. 1954; Rosen and Tucker 1961).

Xiphophorus maculatus (Günther, 1866), popularly known as platy fish, was originally distributed in freshwater environments along the Atlantic slope of Mexico, Belize, and Guatemala (see Results for more details); however, it is now widely introduced to several countries, including Brazil (Lucinda 2003; Fricke et al. 2021b). The aquarium trade is the primary pathway for introduction of this species, as platy fishes are a common in the aquarium hobby as they present a plastic coloration, a wide tolerance to a variety of environmental parameters, and the distinctiveness of being a live-bearing fish (Kallman 1975; Nico and Fuller 2009; Ramos et al. 2020). However, despite being a widely distributed invasive species, the first record of *X. maculatus* for a river system of northeastern Brazil was only published in 2020, from the Municipality of João Pessoa, state of Paraíba (Ramos et al. 2020).

During a recent field expedition, we recorded for the first time *Xiphophorus maculatus* from the state of Maranhão, specifically in the Municipality of São Luís (Fig. 1). This new occurrence is only the second record of this introduced species from northeastern Brazil.

Methods

Sampling methods. The collection was carried out during the daylight, using a seine net (2 m long × 1.8 m high; 2 mm mesh size). Specimens collected for this study were euthanized in a buffered solution of ethyl-3-amino-benzoat-methanesulfonate (MS-222) with a concentration

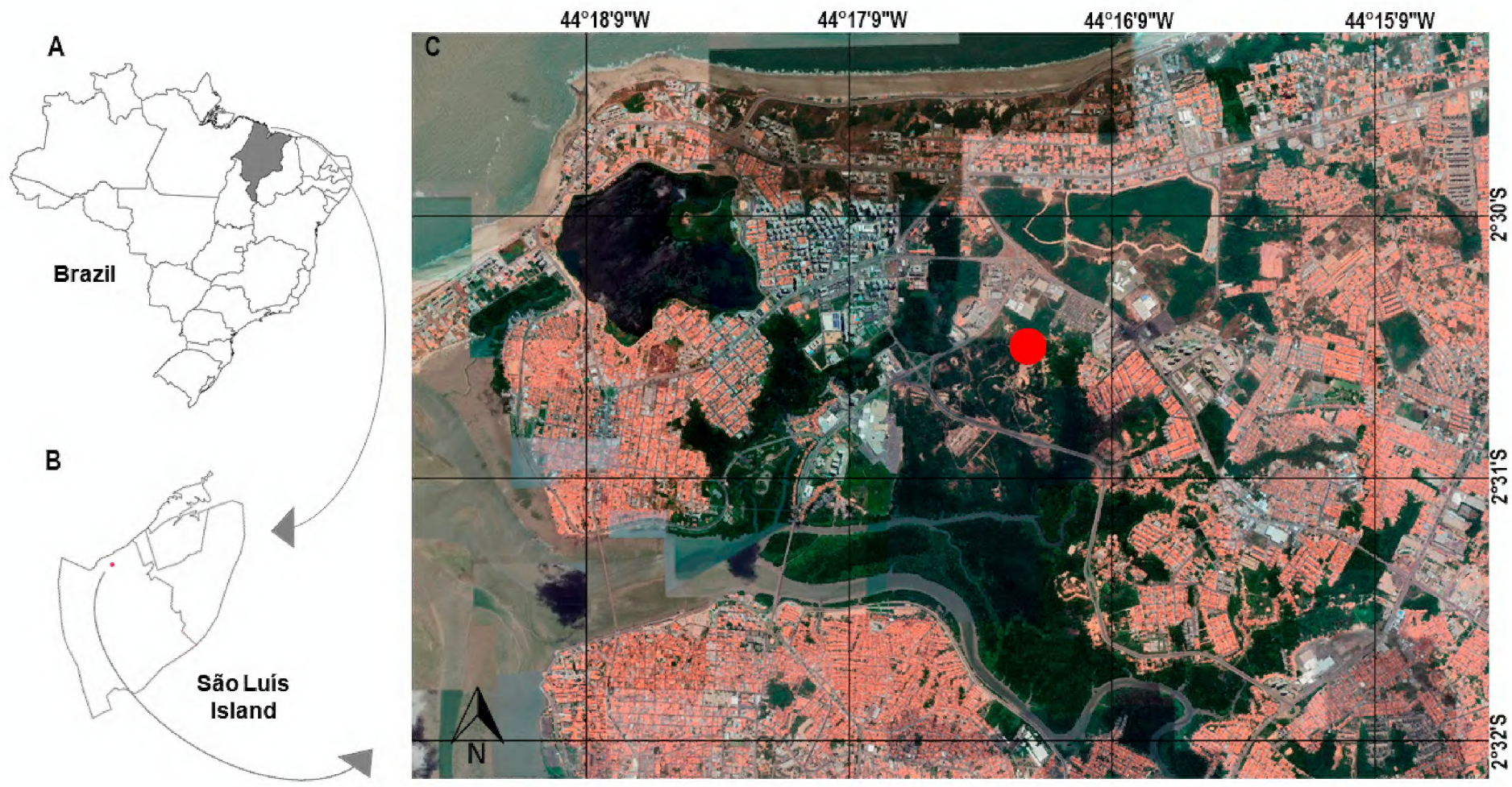

Figure 1. New record of the non-native *Xiphophorus maculatus* in the Anil river basin, Municipality of São Luís, Maranhão, northeastern Brazil. **A.** Brazil, state of Maranhão in grey. **B.** São Luís Island. **C.** Collecting site of the new record (represented by a red dot), satellite image adapted from Google Earth Pro v. 7.3.4.

Figure 2. *Xiphophorus maculatus*. **A.** Male, 19.9 mm SL (CICCAA 02682). **B.** Female, 18.0 mm SL mm SL (CICCAA 02682).

of 250 mg/l until the complete cease of opercular movements. The specimens were later fixed in formalin 10% for 10 days, after which they were preserved in 70% ethanol for long term storage. All the specimens were deposited at the Centro de Ciências Agrárias e Ambientais da Universidade Federal do Maranhão (CICCAA) ichthyological collection. All specimens were sampled under the permit 57414-3 from SISBIO (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais).

Identification. The identification to species used diagnostic features provided by Rosen (1960), longitudinal series of scales, transversal scales, and fin counts following Bragança et al. (2020a), and nomenclature for gonopodial structures following Rosen and Gordon (1953). The standard length (SL) was measured with digital calipers from the upper jaw (premaxilla) to the posterior margin of the hypural plate.

Results

Family Poeciliidae

***Xiphophorus maculatus* (Günther, 1866)**
Figure 2

Material examined. BRAZIL – **Maranhão** • São Luís, Anil river basin, Igarapé Vinhais; 02°30′20.38″S, 044°16′30.55″W; 25.III. 2020; E. Guimarães, J. Santos and P. Brito leg.; 1 ♂, 17.0 mm SL; 1 ♀, 17.9 mm SL, CICCAA 02683 • São Luís, Anil river basin, Igarapé Vinhais; 02°30′20.38″S, 044°16′30.55″W; 25.III. 2020; E. Guimarães, J. Santos and P. Brito leg.; 4 ♂ 16.4–20.4 mm SL; 3 ♀ 17.43–20.3 mm SL, CICCAA 02682.

On 25 March 2021 the water temperature at the site was 26.6 °C, dissolved oxygen was 5.17 mg/l, and the water depth was approximately 70 cm.

Identification. The specimens were identified as *X. maculatus* based on the presence of the following diagnostic characters as defined by Rosen (1960): lower caudal fin rays not elongated in adult males; absence of midlateral stripe; absence of a deep-lying ridge of black pigment midventrally on caudal peduncle; dorsal and anal fins rounded; dorsal fin not sexually dimorphic, usually with a faint or moderate diffuse dusk band near base. Gonopodium without claw at tip of ray 5a, rarely with a minute scythe-shaped or crescent element; distal serrae on ray 4p well developed and erect, seldom retrorse, 4 to 7 in number; ramus of ray 4a curved downward over blade, not hooked, and extending to tip of ray 4p; hook of ray 3 long and slender. The gonopodium tip of *X. maculatus* were illustrated by Rosen (1960: fig. 3B, C, 1979: fig. 29F) and Albornoz-Gárzon and Villa-Navarro (2017: fig. 4). Vertebrae usually number 27, or rarely 26. Scales in

lateral series are 22–25 and usually 23 or 24. Dorsal fin rays 7–10, usually 9 or 10.

Geographic distribution and first record from Maranhão. *Xiphophorus maculatus* originates from freshwater environments along the Atlantic slope of North and Central America in Mexico, Belize, and Guatemala, from Ciudad Veracruz, in Mexico to northern Belize (Lucinda 2003; Fricke et al. 2021b). However, the species have been introduced in several countries, including Brazil (Lucinda 2003; Fricke et al. 2021b). Here, we report the first record of this invasive species in Maranhão, in Igarapé Vinhais (Anil river basin), Municipality of São Luís (Figs. 1, 3). This is only the second record from northeastern Brazil (Ramos et al. 2020).

Discussion

The phylogenetic relationships between *Xiphophorus* species has undergone a major shift with the inclusion of molecular data. Previously, four clades were identified on the basis of color patterns and morphological traits: the northern and southern platys, representing two ancient lineages within *Xiphohorus*, and the northern and southern swordtails, forming a monophyletic group (Rosen 1979; Basolo 1991). This hypothesis suggested that the male elongated fin rays forming a sword-like structure, appeared only once in the evolution of the genus, in the common ancestor shared between the northern and southern swordtails. The more recent molecular phylogenies by Kang et al. (2013) and Jones et al. (2013), on the other hand, indicate an ancient single origin of the swordtail in the common ancestor of all *Xiphophorus*, with a subsequent loss along with the evolution of platys. These molecular studies recovered three major clades of *Xiphophorus*, the southern swordtails, the northern swordtails, and the platy fish, in which the northern platy fish forms a clade and the southern platies are not monophyletic within the platy fish clade. The southern swordtails were recovered as the most ancient lineage in the genus.

Two species of platies, *Xiphophorus variatus* (Meek, 1904) and *X. maculatus*, are widely utilized in the aquarium trade, with both being reported as invasive species.

Figure 3. Collecting site of the new record of *Xiphophorus maculatus*. Igarapé Vinhais (Anil river basin) at Sítio Santa Eulália, Municipality of São Luís, Maranhão, Brazil (02°30′20.38″S, 044°16′30.55″W).

Despite the lack of the sword structure in these two species, they can be easily distinguished by their color pattern and a series of morphological characters (Rosen 1960). *Xiphophorus variatus* differs from *X. maculatus* by the presence of two or more black zigzag midlateral stripes running from the base of caudal peduncle to the opercular membrane, by the presence of two or more oblique black lines extending downward from the midlateral stripes just behind pectoral base, and in having a sexually dimorphic dorsal fin which is higher and more smoothly rounded in adult males than in females. Despite their overlap, other useful characters distinguishing *X. variatus* from *X. maculatus* are the presence of 28 or 29 vertebrae, rarely 27 or 30 in *X. variatus* (vs. 27, rarely 26 in *X. maculatus*); 24–28 scales, usually 26, in the lateral line in *X. variatus* (vs. 22–25, usually 23 or 24 in *X. maculatus*); and 9–14 rays in the dorsal-fin, in *X. variatus* (vs. 7–10, usually 9 or 10 in *X. maculatus*). Phylogenetically, within the platies clade, both species are not closely related, with *X. maculatus* being recovered as a more ancient linage (Kang et al. 2013) or even as sister to all other platy species (Jones et al. 2013), whereas *X. variatus* is recovered as a more derived lineage, sister to the northern platies clade (Jones et al. 2013; Kang et al. 2013).

Despite three decades of field campaigns in the state of Maranhão which surveyed the state's ichthyofauna, *X. maculatus* had not been detected in any previous collections (e.g., Garavello et al. 1998; Piorski 1998; Castro et al. 2002; Piorski et al. 2003; Pinheiro Júnior et al. 2005; Soares 2005; Castro et al. 2010; Barros et al. 2011; Martins and Oliveira 2011; Sousa et al. 2011; Fraga et al. 2012; Ramos et al. 2014; Ribeiro et al. 2014; Matavelli et al. 2015; Melo et al. 2016; Piorski et al. 2017; Abreu et al. 2019, 2020; Brito et al. 2019, 2020; Lima et al. 2019; Teixeira et al. 2019; Guimarães et al. 2020a, 2020b, 2021; Oliveira et al. 2020). However, from the island of São Luís, state of Maranhão, other non-native fishes have been recorded in various aquatic environments (freshwater, brackish, and marine habitats near the coast), including *Butis koilomatodon* (Bleeker, 1849) (Eleotridae), *Omobranchus punctatus* (Valenciennes, 1836) (Blenniidae), *Poecilia mexicana* Steindachner, 1863 (Poeciliidae), and *Poecilia reticulata* (Poeciliidae) (Lasso-Alcalá et al. 2011; Guimarães et al. 2017; Nogueira and Luvizotto-Santos 2018; Bragança et al. 2019, 2020b; Aguiar et al. 2021). A variety of pathways are likely responsible for these introductions, given the small body sizes of these species (Grabowska and Przybylski 2015). *Xiphophorus maculatus*, as well as other poeciliids, due to viviparity, can successfully establish invasive populations starting from one pregnant female (Grapputo et al. 2006; Deacon et al. 2011). Previous habitat invasions by these species due to the aquarium trade, ballast water discharges and stowaways, and mosquito larvae biological control have been suggested (Soares et al. 2012; Magalhães and Jacobi 2013, 2017; Bueno et al. 2021). Our new record of *X. maculatus* is the third invasive poeciliid species occurring in natural environments of the island of São Luís (Nogueira and Luvizotto-Santos 2018; Bragança et al. 2019, 2020b).

Many poeciliid fishes are widespread and phenotypically plastic r-selected species that proliferate rapidly. Their successful establishment in new habitats are often facilitated by the degradation of natural habitats and urbanization of water bodies (Santana et al. 2020). Poecilids have a perceived positive socio-economic value, with respect to economic potential and mosquito-borne disease control, despite no satisfactory studies indicating a dietaru preference for mosquito larvae (Lucinda 2003). However, studies on the ecological impacts of these small fishes are lacking, despite consistently being predicted as having high invasion risk (Mendoza et al. 2015; Weyl et al. 2020). Nonetheless, poeciliids in general are capable of outcompeting native species (Mofu et al. 2019a) and have a high predatory impact on invertebrate abundance and diversity (Tsang and Dudgeon 2021), the extent of which varies with environmental context and local abundance (Mofu et al. 2019b). According to the limiting similarity hypothesis, when functionally similar native and invasive species coexist, there is a likelihood of biotic resistance of native fish assemblages where they are not under stress and the habitat is pristine (MacArthur and Levins 1967). However, this may vary depending on the niche plasticity of both the native and invasive species, as well as localized patterns of resource availability which may allow the invader to occupy a previously unexploited niche or broadening its trophic niche under competition (Dominguez et al. 2021). In Maranhão there are five native poeciliid species: *Poecilia* (*Micropoecilia*) *branneri* Eigennman, 1894, *Poecilia* (*Micropoecilia*) *sarrafae* Bragança & Costa, 2011, *Poecilia* (*Pamphorichtys*) *hollandi* (Henn, 1916), *Poecilia* (*Pamphorichthys*) *araguaiensis* (Costa, 1991), and *Poecilia* (*Poecilia*) *vivipara* Bloch & Schneider, 1801 (Figueiredo 1997; Bragança and Costa 2011; Ramos et al. 2014; Melo et al. 2016; Piorski et al. 2017; Brito et al. 2019, 2020; Guimarães et al. 2020a, 2020b, 2021; Oliveira et al. 2020), as well as diverse yet functionally similar small fish assemblages (Oliveira et al. 2020). Thus, there is a possibility that a successful invasion by *X. maculatus* may present a threat to native species through competition. However, to assess the impact caused by these invasive species in northeastern Brazil, particular ecological conditions should be investigated, such as the abundance of invasive fishes and their distribution and environmental parameters. This is especially important in areas of increased urbanization, which have conditions that facilitate invasions through multiple environmental stressors (Santana et al. 2020; Jackson et al. 2021).

Patterns of increased fish invasions, including those from the aquarium trade, into Neotropical assemblages are attributed to increase in biotic homogenization of megadiverse systems (Tickner et al. 2020; Vitule et al. 2021). Thus, we highlight the first record of the non-native *X. maculatus* in the island of São Luís as a warning for the negative impact of invasive species introductions

in Maranhão, especially on small native species of fishes.

Acknowledgements

Thanks are owed to CAPES (Coordenação de Aperfeiçoamento de pessoal de nível Superior - Finance Code 001) and FAPEMA (Fundação de Amparo à Pesquisa e Desenvolvimento Científico e Tecnológico do Maranhão) for providing financial support for this study, and to Victor de Brito, Igor Souto-Santos, and an anonymous reviewer for the comments, corrections and suggestions.

Authors' Contributions

Conceptualization: FPO, JS. Data curation: ECG, JPS, PSB. Funding acquisition: FPO. Investigation: PHNB. Supervision: ECG, FPO, JPS. Validation: PHNB. Visualization: ECG, FPO, PHNB. Writing – original draft: FPO. Writing – review and editing: ECG, JPS, PSB, JS, PHNB.

References

Abreu JMS, Craig JM, Albert JS, Piorski NM (2019) Historical biogeography of fishes from coastal basins of Maranhão state, northeastern Brazil. Neotropical Ichthyology 17 (2): e180156. https://doi.org/10.1590/1982-0224-20180156

Abreu JMS, Saraiva AC, Albert JS, Piorski NM (2020) Paleogeographic influences on freshwater fish distributions in northeastern Brazil. Journal of South American Earth Sciences 102 (5): 102692. https://doi.org/10.1016/j.jsames.2020.102692

Aguiar RG, Guimarães EC, Brito PS, Ottoni FP, Nunes JLS (2021) Ictiofauna de poças de maré em terraços consolidados do litoral Amazônico Brasileiro. Oecologia Australis 25 (4): 880–888. https://doi.org/10.4257/oeco.2021.2504.09

Albornoz-Gárzon JG, Villa-Navarro FA (2017) Range extension of the invasive fish *Xiphophorus maculatus* (Günther,1866) (Cyprinodontiformes: Poeciliidae) in the upper Magdalena river basin, Colombia. Check List 13 (3): 2149. https://doi.org/10.15560/13.3.2149

Barros MC, Fraga EC, Birindelli JLO (2011) Fishes from the Itapecuru river basin, state of Maranhão, northeast Brazil. Brazilian Journal of Biology 71(2): 375–380. https://doi.org/10.1590/S1519-69842011000300006

Basolo AL (1991) Male swords and female preferences: response. Science 253: 1426–1427.

Bragança PHN, Costa WJEM (2011) *Poecilia sarrafae*, a new poeciliid from the Paraíba and Mearim river basins, northeastern Brazil (Cyprinodontiformes: Cyprinodontoidei). Ichthyological Exploration of Freshwaters 21 (4): 369–376.

Bragança PHN, Amorim PF, Costa WJEM (2018) Pantanodontidae (Teleostei, Cyprinodontiformes), the sister group to all other cyprinodontoid killifishes as inferred by molecular data. Zoosystematics and Evolution 94 (1): 137–145. https://doi.org/10.3897/zse.94.22173

Bragança PHN, Ramos-Junior CC, Guimarães EC, Ottoni FP (2019) Identification of the Mexican Molly, *Poecilia mexicana* (Cyprinodontiformes: Poeciliidae), introduced in Brazil through α-taxonomy and DNA barcoding. Cybium 43 (4): 331–340. https://doi.org/10.26028/cybium/2019-434-003

Bragança PHN, Van der Zee JR, Sonnenberg R, Vreven, EJWMN (2020a) Description of two new miniature species of *Hylopanchax* Poll & Lambert, 1965 (Cyprinodontiformes: Procatopodidae), from northeastern Gabon, with an updated diagnosis of the genus based on morphology, colouration and osteology. Journal of Fish Biology 98 (3): 655–667. https://doi.org/10.1111/jfb.14606

Bragança PHN, Guimarães EC, Brito PS, Ottoni FP (2020b) On the natural occurrence of *Poecilia reticulata* Peters, 1859 (Cyprinodontiformes: Poeciliidae). Cybium 44 (4): 309–316. https://doi.org/10.26028/cybium/2020-444-002

Bueno ML, Magalhães ALB, Andrade Neto FR, Alves CBM, Rosa DM, Junqueira NT, Pessali TC, Pompeu PS, Zenni RD (2021) Alien fish fauna of southeastern Brazil: species status, introduction pathways, distribution and impacts. Biological Invasions 23: 3021–3034. https://doi.org/10.1007/s10530-021-02564-x

Brito PS, Guimarães EC, Ferreira BRA, Ottoni FP, Piorski NM (2019) Freshwater fishes of the Parque Nacional dos Lençóis Maranhenses and adjacent areas. Biota Neotropica 19(3): E20180660. https://doi.org/10.1590/1676-0611-bn-2018-0660

Brito PS, Guimarães EC, Ferreira BRA, Santo SJP, Amaral YT, Ottoni FP (2020) Updated and supplementary data on Brito et al. (2020): Freshwater fishes of the Parque Nacional dos Lençóis Maranhenses and adjacent areas. Ichthyological Contributions of Pecescriollos 73: 1–17.

Castro ACL, Piorski NM, Pinheiro Junior JR (2002) Avaliação qualitativa da ictiofauna da Lagoa da Jansen, São Luís-MA. Boletim do Laboratório de Hidrobiologia 15: 39–50.

Castro ACL, Castro KDD, Porto HLR (2010) Distribuição da assembléia de peixes na área de influência de uma indústria de alumínio na ilha de São Luís-MA. Arquivos de Ciências do Mar 43: 71–78.

Clark E, Kamrin RP (1951) The role of the pelvic fins in the copulatory act of certain poeciliid fishes. American Museum Novitates 509: 1–14.

Clark E, Aronson LR, Gordon M (1954) Mating behavior patterns in two sympatric species of xiphophorin fishes: their inheritance and significance in sexual isolation. Bulletin of the American Museum of Natural History 103 (2): 135–226.

Costa WJEM (1991) Description d'une novelle espèce du genre *Pamphorichthys* (Cyprinodontiformes: Poeciliidae) du bassin de l'Araguaia, Brésil. Revue Française d'Aquariologie 18: 39–42.

Deacon AE, Ramnarine IW, Magurran AE (2011) How reproductive ecology contributes to the spread of a globally invasive gfish. PLoS ONE 6 (9): e24416. https://doi.org/10.1371/journal.pone.0024416

Dominguez AV, South J, Britton JR (2021) Predicting the competitive interactions and trophic niche consequences of a globally invasive fish with threatened native species. Journal of Animal Ecology 90: 2651– 2662. https://doi.org/10.1111/1365-2656.13571

Figueiredo CAA (1997) Revisão taxonômica e filogenia de *Pamphorichthys* Regan, 1913 (Cyprinodontiformes; Poeciliidae). PhD thesis, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil, 139 pp.

Fraga E, Birindelli JLO, Azevedo CAS, Barros MCA (2012) Ictiofauna da Área de Proteção Ambiental Municipal do Inhamum, Caxias/MA. In: Barros MC (Ed.) Biodiversidade na Área de Proteção Ambiental Municipal do Inhamum. UEMA, São Luís, Brazil, 107–115.

Fricke R, Eschmeyer WN, Fong JD (2021a) Species by family/subfamily. http://researcharchive.calacademy.org/research/ichthyology/catalog/SpeciesByFamily.asp. California Academy of Sciences, San Francisco, USA. Accessed on: 2021-6-08.

Fricke R., Eschmeyer WN, Van der Laan R. (2021b) Eschmeyer's catalog of fishes: genera, species, references. http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp. California Academy of Sciences, San Francisco, USA. Accessed on: 2021-6-08.

Garavello JC, Rocha O, Espíndola EG, Rietzler AC, Leal AC (1998) Diversity of fauna in the interdunal lakes of "Lençois Maranhenses". Part 2. The ichthyofauna. Anais da Academia Brasileira de Ciências 70 (4): 797–803.

Grabowska J, Przybylski M (2015) Life-history traits of non-native freshwater fish invaders differentiate them from natives in the Central European bioregion. Reviews in Fish Biology and Fisheries 25: 165–178. https://doi.org/10.1007/s11160-014-9375-5

Grapputo A, Bisazza A, Pilastro A (2006) Invasion success despite reduction of genetic diversity in the European populations of eastern mosquitofish (*Gambusia holbrooki*). Italian Journal of Zoology 73 (1): 67–73. https://doi.org/10.1080/11250000500502111

Guimarães EC, Brito PS, Ottoni FP (2017) First record of *Butis koilomatodon* (Bleeker, 1849) (Gobiiformes: Eleotridae) for the Maranhão state, northeastern Brazil: a case of bioinvasion. Cybium 41 (3): 299–300. https://doi.org/10.26028/cybium/2017-413-009

Guimarães EC, Brito PS, Gonçalves CS, Ottoni FP (2020) An inventory of ichthyofauna of the Pindaré river drainage, Mearim river basin, northeastern Brazil. Biota Neotropica 20 (4): e20201023. https://doi.org/10.1590/1676-0611-bn-2020-1023

Guimarães EC, Brito PS, Ottoni FP (2020b) Peixes. In: Dornas RAP, Rolim SG (Eds.) Fauna de vertebrados do entorno da estrada de Ferro Carajás. Editora Rupestre, Belo Horizonte, Brazil, 32–51.

Guimarães EC, Oliveira RF, Brito PS, Vieira LO, Santos JP, Oliveira ES, Aguiar RG, Katz AM, Lopes DFC, Nunes JLS, Ottoni FP (2021) Biodiversidade, potencialidades ornamentais e guia ilustrado dos peixes da mata Itamacaoca município de Chapadinha-MA. In: Guimarães EC, Dias LJBS (Eds.) Instituto Maranhense de Estudos Socioeconômicos e Cartográficos (IMESC), São Luís, Brazil, 45.

Jackson MC, Pawar S, Woodward G (2021) The temporal dynamics of multiple stressor effects: from individuals to ecosystems. Trends in Ecology & Evolution 36 (5): 402–410. https://doi.org/10.1016/j.tree.2021.01.005

Jones JC, Fan S, Franchini P, Schartl M, Meyer A (2013) The evolutionary history of *Xiphophorus* fish and their sexually selected sword: a genome-wide approach using restriction site-associated DNA sequencing. Molecular Ecology 22 (11): 2986–3001. https://doi.org/10.1111/mec.12269

Kallman KD (1975) The platyfish, *Xiphophorus maculatus*. In: King RC (Ed.) Handbook of genetics. Volume 4. Vertebrates of Genetic Interest. Springer, Boston, USA, 81–132. https://doi.org/10.1007/978-1-4613-4470-4_6

Kalinkat G, Jähnig SC, Jeschke JM (2017) Extinction risk allometry in freshwaters. Proceedings of the National Academy of Sciences of the United States of America 114 (48): E10263–E10264. https://doi.org/10.1073/pnas.1717087114

Kang JH, Schartl M, Walter RB, Meyer A (2013) Comprehensive phylogenetic analysis of all species of swordtails and platies (Pisces: Genus Xiphophorus) uncovers a hybrid origin of a swordtail fish, Xiphophorus monticolus, and demonstrates that the sexually selected sword originated in the ancestral lineage of the genus, but was lost again secondarily. BMC Evolutionary Biology 13: 25. https://doi.org/10.1186/1471-2148-13-25

Lasso-Alcalá O, Nunes JLS, Lasso C, Posada J, Robertson R, Piorski NM, TJV, Giarrizzo T, Gondolo G (2011) Invasion of the Indo-Pacific Blenny *Omobranchus punctatus* (Perciformes: Blenniidae) on the Atlantic Coast of Central and South America. Neotropical Ichthyology 9 (3): 571–578. https://doi.org/10.1590/S1679-62252011000300010

Lima RC, Almeida MS, Barros M, Fraga E (2019) Identificação e caracterização molecular de peixes da APA do Inhamum, Leste Maranhense, Brasil. In: Silva Neto BR (Ed.) Conceitos Básicos da Genética. Atena Editora, Ponta Grossa, Brazil, 151–168.

Lucinda PHF (2003) Family Poeciliidae. In: Reis RE, Kullander SO, Ferraris Jr C. (Eds.) Check list of the freshwater fishes. EDIPUCRS, Porto Alegre, Brazil, 555–581.

Lucinda PHF, Reis RE (2005) Systematics of the subfamily Poeciliinae Bonaparte (Cyprinodontiformes: Poeciliidae), with an emphasis on the tribe Cnesterodontini Hubbs. Neotropical Ichthyology 3: 1–60. https://doi.org/10.1590/S1679-62252005000100001

Macarthur R, Levis R (1967) The limiting similarity, convergence, and divergence of coexisting species. The American Naturalist 101 (921): 377–385.

Magalhães ALB, Jacobi CM (2013) Invasion risks posed by ornamental freshwater fish trade to southeastern Brazilian rivers. Neotropical Ichthyology 11 (2): 433–441. https://doi.org/10.1590/S1679-62252013005000003

Magalhães ALB, Jacobi CM (2017) Colorful invasion in permissive Neotropical ecosystems: establishment of ornamental non-native poeciliids of the genera *Poecilia*/*Xiphophorus* (Cyprinodontiformes: Poeciliidae) and management alternatives. Neotropical Ichthyology 15 (1): e160094. https://doi.org/10.1590/1982-0224-20160094

Martins MB, Oliveira TG (2011) Amazônia maranhense: diversidade e conservação. MPEG, Belém, Brazil, 329 pp.

Matavelli R, Campos AM, Vale J, Piorski NM, Pompeu OS (2015) Ichthyofauna sampled with tadpoles in northeastern Maranhão state, Brazil. Check List 11 (1): 1550. https://doi.org/10.15560/11.1.1550

Melo FAG, Buckup PA, Ramos TPA, Souza AKN, Silva CMA, Costa TC, Torres AR (2016) Fish fauna of the lower course of the Parnaíba river, northeastern Brazil. Boletim do Museu de Biologia Mello Leitão 38 (4): 363–400.

Mendoza R, Luna S, Aguilera C (2015) Risk assessment of the ornamental fish trade in Mexico: analysis of freshwater species and effectiveness of the FISK (Fish Invasiveness Screening Kit). Biological Invasions 17 (12): 3491–3502. https://doi.org/10.1007/s10530-015-0973-5

Mofu L, South J, Wasserman RJ, Dalu T, Woodford DJ, Dick JTA, Weyl OLF (2019a) Inter-specific differences in invader and native fish functional responses illustrate neutral effects on prey but superior invader competitive ability. Freshwater Biology 64: 1655–1663. https://doi.org/10.1111/fwb.13361

Mofu L, Cuthbert RN, Dalu T, Woodford DJ, Wasserman RJ, Dick JTA, Weyl OLF (2019b) Impacts of non-native fishes under a seasonal temperature gradient are forecasted using functional responses and abundances. NeoBiota 49: 57–75. https://doi.org/10.3897/neobiota.49.34986

Nico L, Fuller P (2009) *Xiphophorus maculatus*. Nonindigenous aquatic species database. USGS, Gainesville, Florida, USA, unpaginated. http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=872. Accessed on: 2021-06-08.

Nogueira JLF, Luvizotto-Santos R (2018) Tolerância de *Poecilia* spp. à salinidade: uso em bioensaios com amostras salinizadas. Boletim do Laboratório de Hidrobiologia 28 (1): 23–30.

Oliveira EDS, Guimarães EC, Brito OS, Vieira LDO, Oliveira RFD, Campos DS, Ottoni FP (2020) Ichthyofauna of the Mata de Itamacaoca, an urban protected area from the upper Munim River basin, northern Brazilian Cerrado. Biota Neotropica 20 (4): e20201116. https://doi.org/10.1590/1676-0611-BN-2020-1116

Pinheiro Júnior JR, Castro ACL, Gomes LN (2005) Fish community structure in Anil River estuary, São Luís Island, Maranhão state. Arquivo de Ciências do Mar 38: 29–37.

Piorski NM, Castro ACL, Pereira LG, Muniz MEL (1998) Ictiofauna do trecho inferior do Rio Itapecuru, nordeste do Brasil. Boletim do Laboratório de Hidrobiologia 11: 15–24.

Piorski NM, Castro ACL, Pinheiro CUB (2003) A prática da pesca entre os grupos indígenas das bacias dos rios Pindaré e Turiaçu, no estado do Maranhão, nordeste do Brasil. Boletim do Laboratório de Hidrobiologia 16: 67–74.

Piorski NM, Ferreira BRA, Guimarães EC, Ottoni FP, Nunes JLS, Brito PS (2017) Peixes do Parque Nacional dos Lençóis Maranhenses. EDUFMA, São Luís, Brazil, 189 pp.

Ramos TPA, Ramos RTC, Ramos SAQA (2014) Ichthyofauna of the Parnaíba river basin, northeastern Brazil. Biota Neotropica 14 (1): 1–8. https://doi.org/10.1590/S1676-06020140039

Ramos TPA, Carvalho Rocha YGP, Lustosa Costa SY, Barbosa JEL (2020) First record of non-native platyfish, *Xiphophorus maculatus* (Günther, 1866) (Cyprinodontiformes, Poeciliidae), in the Jaguaribe river basin, northeastern Brazil. Check List 16 (5): 1159–1164. https://doi.org/10.15560/16.5.1159

Regan CT (1913) A revision of the cyprinodont fishes of the subfamily Poeciliinae. Proceedings of the Zoological Society of London 4: 977–1018.

Reznick DN, Furness AI, Meredith RW, Springer MS (2017) The origin and biogeographic diversification of fishes in the family Poeciliidae. PLoS ONE 12 (3): e0172546. https://doi.org/10.1371/journal. pone.0172546

Ribeiro MFR, Piorski NM, Almeida ZS, Nunes JLS (2014) Fish aggregating known as moita, an artisanal fishing technique performed in the Munim River, state of Maranhão, Brazil. Boletim Instituto de Pesca 40 (4): 677–682.

Rosen DE (1960) Middle-American pociliid fishes of the genus *Xiphophorus*. Bulletin of the Florida State Museum Biological Sciences 5 (4): 57–242.

Rosen DE, Gordon M (1953) Functional anatomy and evolution of male genitalia in poeciliid fishes. Zoologica 38: 1–47.

Rosen DE, Bailey RM (1963) The poeciliid fishes (Cyprinodontiformes)—their structure, zoogeography and systematics. Bulletin of the American Museum of Natural History 126: 1–176.

Rosen DE, Tucker A (1961) Evolution of secondary sexual characters and sexual behavior patterns in a family of viviparous fishes (Cyprinodontiformes: Poeciliidae). Copeia 2: 201–212.

Rosen DE (1979) Fishes from the uplands and intermontane basics of Guatemala: revisionary studies and comparative biogeography. Bulletin of the American Museum of Natural History 162: 267–376.

Santana MP, Manna LR, Frauendorf TC, Zandonà E, Mazzoni, R, El-Sabaawi, R (2020) Urbanization can increase the invasive potential of alien species. Journal of Animal Ecology 89: 2345– 2355. https://doi.org/10.1111/1365-2656.13293

Soares EC (2005) Peixes do Mearim. Instituto Geia, São Luís, Brazil, 142 pp.

Soares BE, Ruffeil TOB, Montag LFA (2012) Occurrence of the non-native sleeper *Butis koilomatodon* (Bleeker, 1849) (Perciformes: Eleotridae) in the Amazon coastal zone, Brazil. BioInvasions Records 1 (2): 95–99. https://doi.org/10.3391/bir.2012.1.2.02

Sousa MRJ, Castro ACL, Silva MHL (2011) Comunidade de peixes como indicador de qualidade ambiental na área de influência da indústria ALUMAR, ilha de São Luís - MA. Boletim do Laboratório de Hidrobiologia 24: 1–8.

Teixeira BRS, Barros MC, Fraga EC (2019) DNA barcoding confirma a ocorrência de espécies amazônicas na ictiofauna do rio Turiaçu, Maranhão/Brasil. In: Silva Neto BR (Ed.) Conceitos Básicos da Genética. Atena Editora, Ponta Grossa, Brazil, 98–1104.

Trexler JC (1989) Phenotypic plasticity in poeciliid life histories. In: Meffe A, Snelson FF (Eds.) The ecology and evolution of poeciliid fishes (Poeciliidae). Prentice Hall, Englewood Cliffs, USA, 201–213.

Tsang AHF, Dudgeon DA (2021) A comparison of the ecological effects of two invasive poeciliids and two native fishes: a mesocosm approach. Biological Invasions 23: 1517–1532. https://doi.org/10.1007/s10530-020-02455-7

Tickner D, Opperman JJ, Abell R, Acreman M, Arthington AH, Bunn SE, Cooke SJ, Dalton J, Darwall W, Edwards G, Harrison I, Hughes K, Jones T, Leclère D, Lynch AJ, Leonard P, McClain ME, Muruven D, Olden JD, Ormerod SJ, Robinson J, Tharme RE, Thieme M, Tockner K, Wright M, Young L (2020) Bending the curve of global freshwater biodiversity loss: an emergency recovery plan. BioScience 70 (4): 330–342. https://doi.org/10.1093/biosci/biaa002

Vitule JRS, Occhi TVT, Carneiro L, Daga VS, Frehse FA, Bezerra LAV, Forneck S, Pereira HS, Freitas MO, Hegel CGZ, Abilhoa V, Grombone-Guaratini MT, Queiroz-Sousa J, Pivello VR, Silva-Matos DM, Oliveira I, Toledo LF, Vallejos MAV, Zenni RD, Ford AGP, Braga RR (2021) Non-native species introductions, invasions, and biotic homogenization in the Atlantic Forest. In: Marques MCM, Grelle CEV (Eds.) The Atlantic Forest. https://doi.org/10.1007/978-3-030-55322-7_13

Weyl OLF, Ellender BR, Wassermann RJ, Truter M, Dalu T, Zengeya TA, Smit NJ (2020) Alien freshwater fauna in South Africa. In: van Wilgen B, Measey J, Richardson D, Wilson J, Zengeya T (Eds.) Biological invasions in South Africa. Invading Nature – Springer Series in Invasion Ecology, 14. Springer, Cham, Switzerland, 153–183. https://doi.org/10.1007/978-3-030-32394-3_6